Use of a multi wavelength integrating Nephelometer to determine particle concentration and size

Herbert Schloesser, American Ecotech L.C., Factory D, 100 Elm Street, Warren, RI, 02885

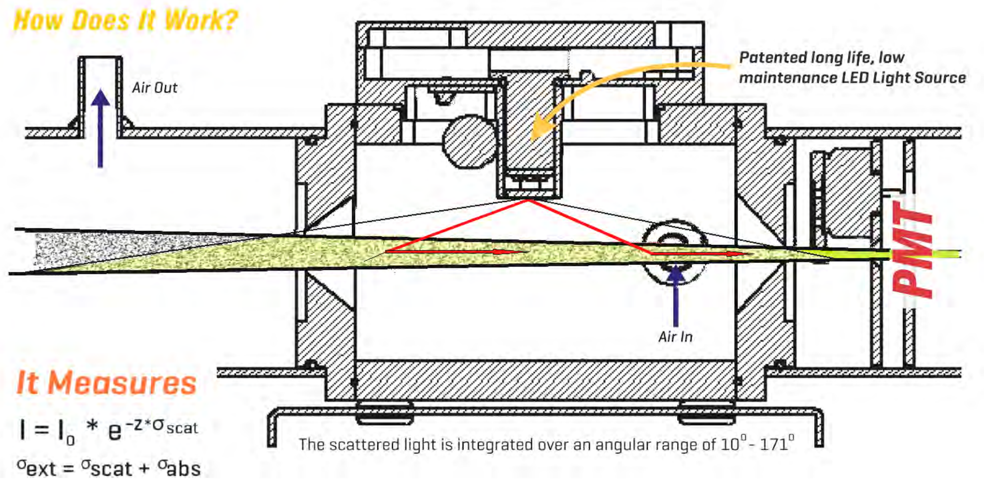
Introduction

The US-EPA has emphasized the importance of measuring pollutant concentrations near highly traveled roads. Measuring particle concentration and other properties is an important step in finding answers as to how traffic contributes to the pollutant mix in a given area. Setting up instruments in these locations is not always easy. Occasionally there are shelters available near the roads to be measured. The Picture below shows a typical setup next to I-40 in Raleigh, NC.

The **Aurora 3000** Nephelometer is set up outside the main container in an weatherproof housing. The upper part of the housing contains the Nephelometer and the lower part acts as a stand and contains the CO_2 cylinder used to calibrate and remotely check the instrument.

Aurora 3000 – 3 wavelength Integrating Nephelometer

The key components of the **Aurora 3000** are a 3 wavelength LED light source, a photomultiplier (PMT) and a reference shutter module to create a zero and reference light. A light trap prevents reflection of scattered light back to the PMT. Barometric pressure and air temperature are also measured.



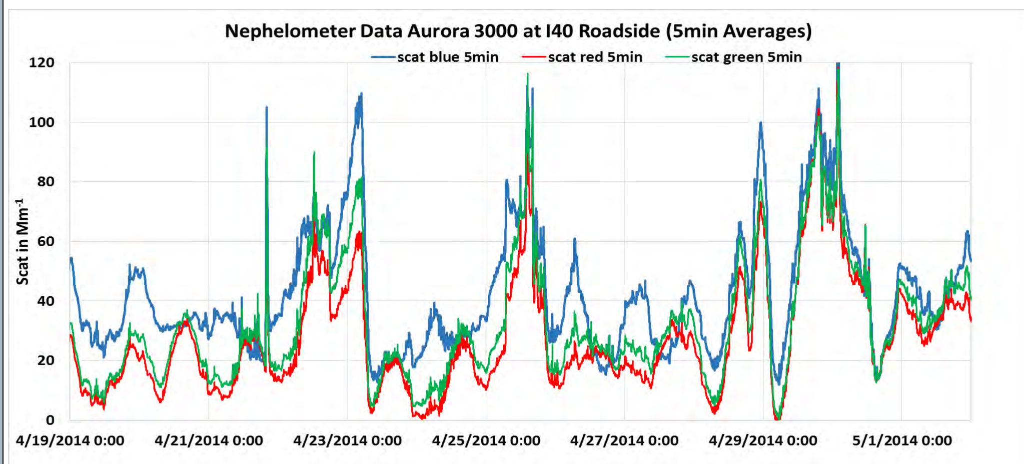
The light from the LED light source illuminates particles inside the measurement cell. Particles inside the PMT viewing cone reflect light towards the PMT on the right. Dependent on the position of the particle in the measurement cone a different scattering angle is measured. The elongated design allows to measure scattering angles from 10° to 171°.

The measured intensity B is described by $B = I_0/y \int_{\phi_1}^{\phi_2} \beta(\phi) \sin\phi \, d\phi$

Aurora light source produces a cosine (Lambertian) intensity profile thus the Integration results in $B \approx (I_0/y) * (\sigma_{scat}/2\pi)$

$$\sigma_{scat} = k * B / I_o$$

Measurement Data Near Roadside I-40 Raleigh, NC



Shown above are, 5 min averages of the measured scattering coefficients for the 3 different wavelengths over a time period of about 14 days. Typically the blue scattering gives the highest reading while the red is the lowest. At a closer look, one will notice that there are times when the ratios change quite a bit. What is noticeable here are the very low noise level in these measurements compared to other short term methods. The detection limit for the Aurora 3000 is typical at 0.3 Mm^{-1} for a 1 min measurement.

Scattering Ångström Exponent

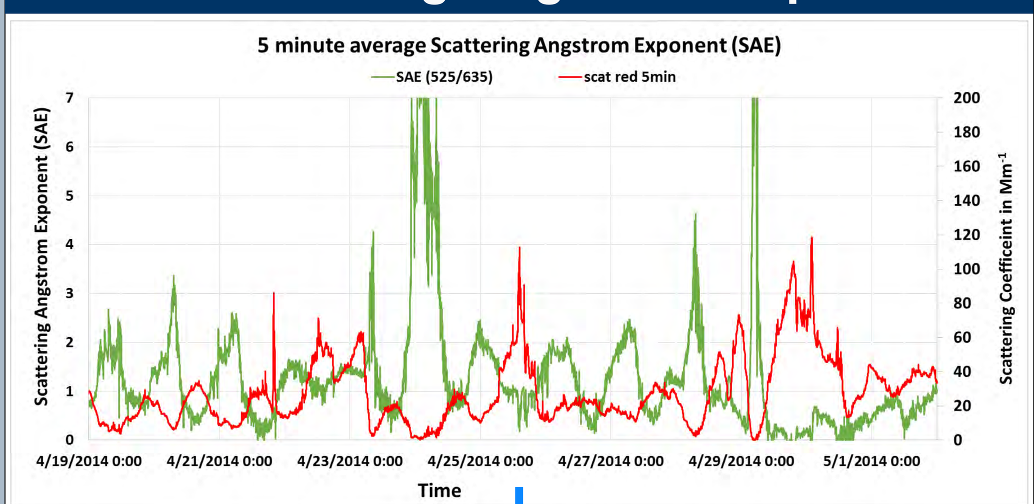
The Ångström Exponent (Å) expresses the spectral dependence of aerosol optical depth (τ) (or scattering coefficient, absorption coefficient, etc.) with the wavelength of light (λ) as inverse power law:

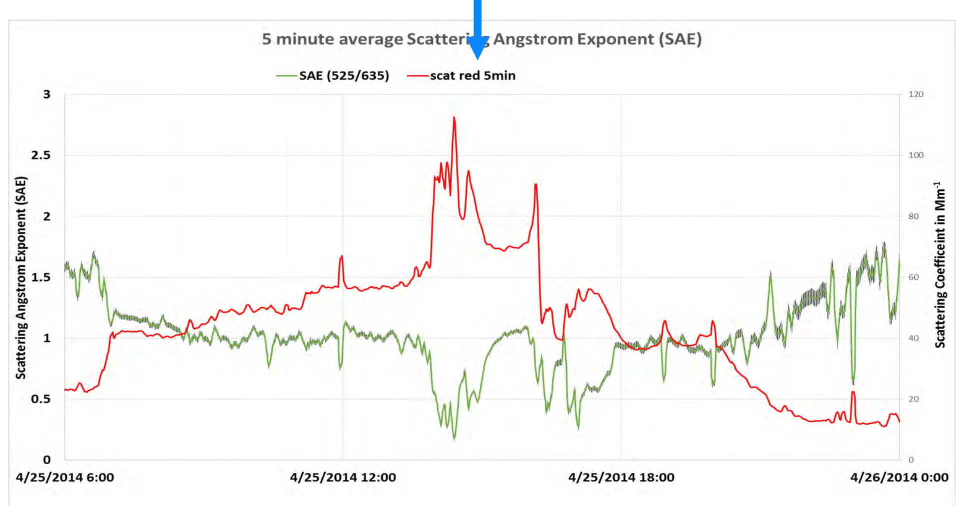
$$\sigma_{scat} \propto \lambda^{-Å}$$

The Ångström exponent is inversely related to the average size of aerosol particles: the smaller the particles, the larger the exponent. The exponent can be obtained from a two wavelength measurement of σ_{scat} by following relationship:

$$Å = \frac{\ln(\sigma_{\lambda_1}) - \ln(\sigma_{\lambda_2})}{\ln(\lambda_1) - \ln(\lambda_2)}$$

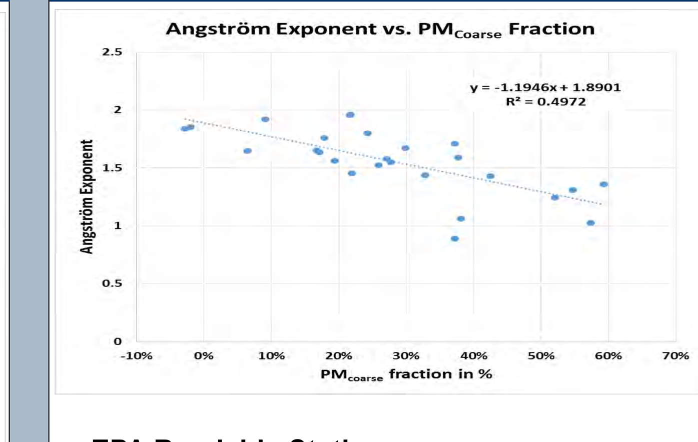
Generating Size specific information with Scattering Ångström Exponent





Here the red scattering coefficient is shown vs. the Ångström coefficient. Generally some diurnal trends can be seen. During daytime particle sizes are bigger and concentrations increase. In the lower expanded section short term changes of particle sizes and their contribution to the scattering coefficient can be identified. The errors of this method are within the low noise band and show the methods high precision.

Lower Scattering Ångström Exponent – bigger particles



Daily averages for the SAE vs PM_{Coarse} fraction show that a shift of average particle diameter towards higher diameters causes the average Ångström exponent to drop. Ångström Exponents > 1.9 are mainly $PM_{2.5}$ and smaller

EPA Roadside Station
(Data Feb 2014-April 2014)

Average concentration is higher from roadside showing road influence in particle pollution

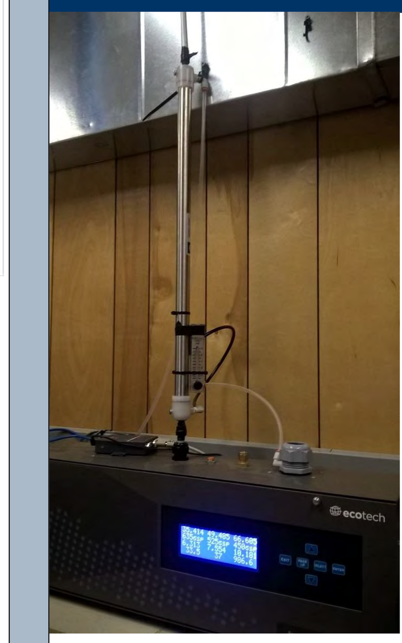
Ångström Exponent is smaller towards road indicating bigger particles as background from wooded area

Wind profile shows peaks along the road directions

Ångström Exponent – for source apportionment

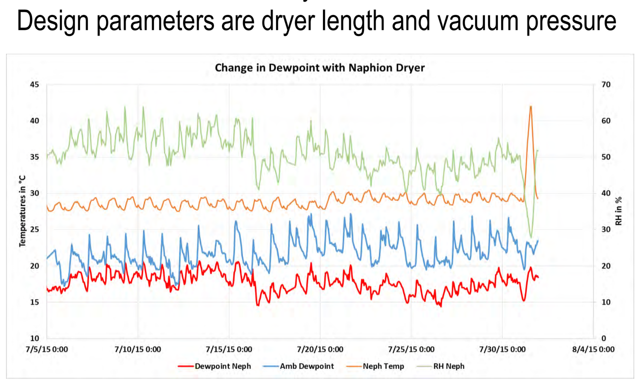
Direction of higher concentration and low Ångström numbers are the same indicating bigger (coarse) particles coming from there. The aerial view reveals a construction site very close by, where construction work was likely being performed causing a dust cloud to impact the station. Concentration levels from other directions and their respective Ångström exponents can give estimation of the influence from this construction site to the total daily measurement. This influence can then be deducted from roadside studies if needed.

Influence of Humidity

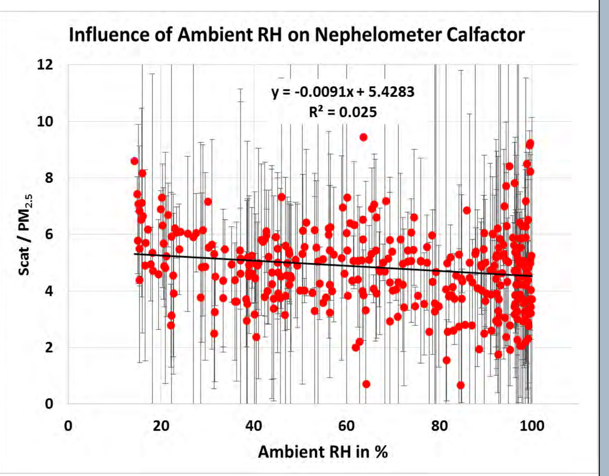


"Dry-Mode" with new "Naphion" Dryer
To avoid losses of volatile particles

Exhaust air of Nephelometer is used in counter flow geometry
The internal RH sensor controls the separate Dryer Pump
Instead of the built in Heater with 24" Dryer the dew point is reduced by 6 °C – 8 °C
Design parameters are dryer length and vacuum pressure

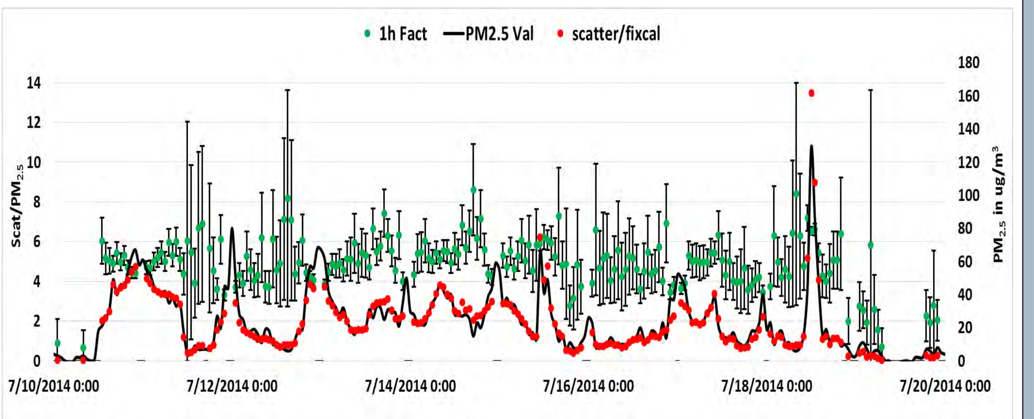


The Nephelometer at the Tumbler Ridge site is not operated in the visibility mode but with an internal heater RH setting of <40%, significantly limiting the influence of RH on the calibration factor as shown on the left.

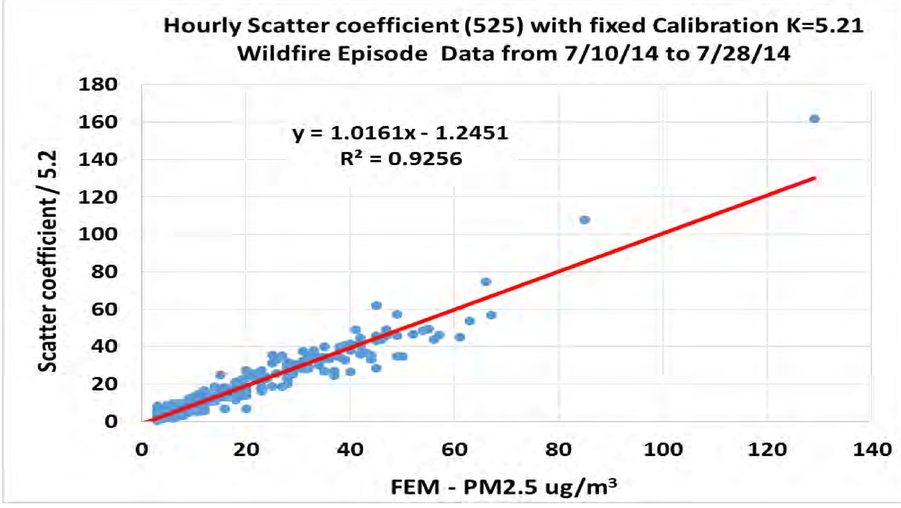


Nephelometers and $PM_{2.5}$

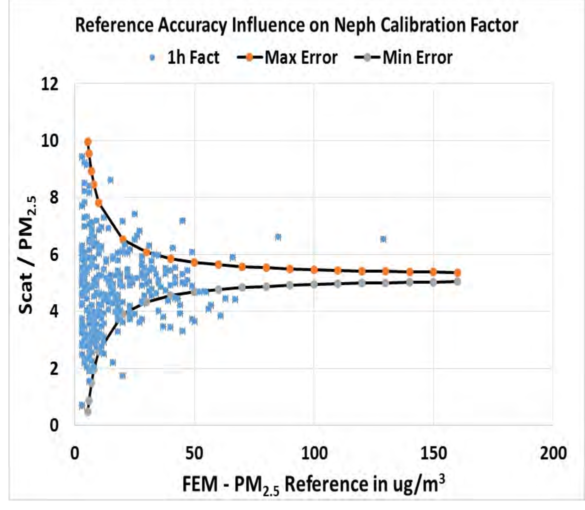
Nephelometers measure predominantly fine particulates. The following Graph shows a comparison with a FEM-BAM-1020 $PM_{2.5}$ System at a rural site near Tumbler Ridge, BC, Canada. The $PM_{2.5}$ hourly concentration is compared to the "green" scattering coefficient scaled by an average factor of 5.2. The data points with the error bars show the actual hourly "calibration" factor, by dividing σ_{scat} / FEM-$PM_{2.5}$



* Error Bars representing the accuracy of the hourly "calibration" factor. The main influence is from the FEM instrument error



The simple fixed factor calibration of σ_{scat} in this time period results in a very good correlation factor of R^2=0.926 for hourly averages between the Nephelometer and the FEM - $PM_{2.5}$ Method



Note: The shown error bars were all based on a σ=2.5µg/m³ BAM value. The influence of this error can be seen in the picture left where the 2 sigma limits have been calculated and with the actual data compared.

Conclusions

Integrating Nephelometers are a valuable tool to study short term changes in aerosol concentrations. The use of the Ångström factor method gives another dimension to the measurement as changes in particulate size distributions within the PM concentrations can be seen. The use of multi wavelength instruments are key for this approach. The accuracy of the Aurora 3000 is typically 0.3Mm^{-1} for a 1 minute average this would translate to about 0.058 µg/m³.
The Ångström Exponent method allows for a identification of aerosol signatures outside the regular site mix and can help to estimate the influence of irregular events (e.g. scattering information can help to identify biomass burning effects, as the organic carbon content is usually high).

Acknowledgments

Sue Kimbrough and Richard Snow, US-EPA Office of Research and Development
Ken Buckley, Georgia DNR

Contact information

American Ecotech, L.C.
Factory D, 100 Elm Street (P.O. Box 311)
Warren, RI 02885
Tel: 877-247-0403
www.AmericanEcotech.com
Email:hschloesser@AmericanEcotech.com